HEADQUARTERS QUARTERMASTER RESEARCH AND ENGINEERING COMMAND, US ARMY
Quartermaster Research and Engineering Center
Natick, Massachusetts

CHEMICALS AND PLASTICS DIVISION
Plastics Section Report No. 4

EVALUATION OF ENERGY DISSIPATING MATERIALS FOR USE
IN AERIAL DELIVERY OF C-RATIONS
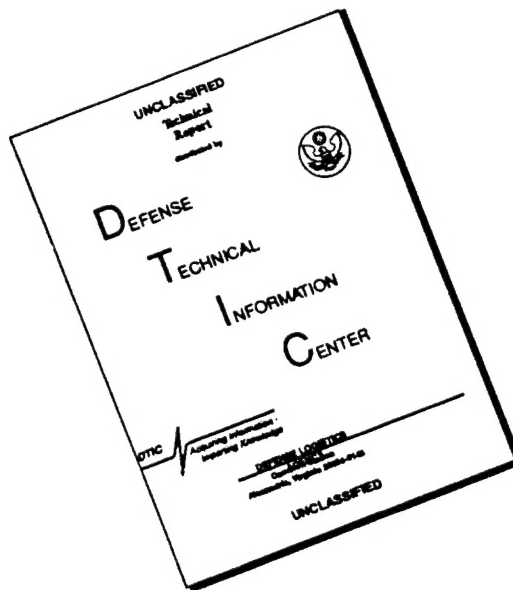
By
Helen Wong
Protective Materiel Branch

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Title

EVALUATION OF ENERGY DISSIPATING MATERIALS FOR USE
IN AERIAL DELIVERY OF C-RATIONS

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A series of experiments, including energy absorption measurements by static methods, were devised to determine the best method to statically test and properly rate materials for use in high velocity aerial delivery of supplies.

The tests reported herein cover the measurements and comparative rating of 25 widely assorted materials such as hair fibers, plastics, foamed glass, wood and metal cylinders.

TABLE OF CONTENTS

SUMMARY

A value of 100 - 200 lbs/square inch stress under static low speed compression test is established as the minimum for screening materials for potential application as energy dissipators in aerial delivery of C-rations.

Twenty-five materials were tested statically in compression at various low speeds on an Instron tester. Of these, thirteen including hair felt, flexible polyester urethane and vinyl foams were found to be unsatisfactory due to low energy dissipation values combined with high resilience. Some experimental flexible polyethylene foams, polystyrene beads and semi-rigid vinyl foams gave acceptable stress values but their resilience is too high. Rigid balsa blocks are unsatisfactory due to low energy dissipation. The stress values for rigid acrylate foams, hydrous calcium silicate, rigid epoxy resin and foamed aluminum are higher than the required minimum but the densities of these materials are too high for application in aerial delivery.

Eight materials, such as rigid polyurethane and polystyrene foams, resin impregnated glass fibers, fibrous silicate blocks (asbestos) experimental and commercial Foamglas, metal cans and polystyrene beads are found to be potentially suitable for application as aerial delivery energy dissipators.

Low density cellular and foamed materials have superior energy dissipation characteristics to more dense materials.

EVALUATION OF ENERGY DISSIPATING MATERIALS FOR USE IN AERIAL DELIVERY OF C-RATIONS

INTRODUCTION

Increased mobility inherent in modern warfare demands a quick and accurate means of supply to provide the combat soldier with food, clothing and equipment. Since the fastest delivery is by air, a method is required so that the dropped items land intact at the desired location. Current methods of aerial supply employ large parachutes as descent retarding devices. However, due to the size of these retarders, the accuracy of aerial drops is diminished due to wind drift. Consequently, if dropped items are remote, even though intact, they are of no use to the potential receivers. While a drop is more accurate with the elimination of the retarder, without cushioning some items would be rendered useless from damage upon impact with the ground.

A more practical system would be to use a small retarder along with a cushioning material to absorb the load energy upon impact. It is required that the cushioning material dissipate all the kinetic energy of the system at a stress value below the breaking strength (hereinafter called the fragility limit) of the dropped item. Other important characteristics of the cushioning material are its ability to deform uniformly upon compression throughout at least 75 percent of its volume and minimum resilience in order to utilize its energy dissipation properties to the maximum with a minimum bounce or return of the load platform upon impact with the ground.

Since actual aerial drop tests are expensive and time consuming, static laboratory tests were made on a number of different materials to determine their behavior under compression. The criteria of low resilience and high unit energy dissipation value under a 100-200 pounds/square inch stress were employed in the tests to evaluate potential energy dissipators.

Hair fibers, plastics, inorganic materials, wood and metal cans were investigated for potential application as energy dissipators in the aerial delivery of C-rations. A description and discussion is given of each candidate material tested.

MATERIALS

PART I FIBERS

Introduction

Various types of fibrous materials are used commercially in the packing
and packaging of items for shipment and in seat cushions. These materials
have been found to be adequate in the absorption of the low velocity shock
encountered under usual shipping conditions. Since air dropped items also
require a shock absorber, representative fibrous materials were evaluated as
possible aerial delivery energy dissipators.

Section A
Hairs

Felt Pads

Static compression tests were conducted on samples of felt shock pads
which have been used as an aerial delivery cushioning material. Although
actual field tests had proved that felt pads were inadequate as an energy
dissipator, laboratory tests were made to establish some basis on which to
screen other materials for application as energy dissipators. Twelve samples
were compressed to the bottoming point at 50 percent deformation indicating
that only one-half of the cushion thickness can be utilized effectively. A
considerable variation was found in the data which may be due to the difference
in density of the material or to the speed of testing. Since a high resi-
lience of 35 percent was obtained along with very low energy dissipation
values (Figure 1), static laboratory compression tests confirm the fact that
felt pads are inadequate as a cushioning material for high velocity aerial
drops.

PART II PLASTICS

Introduction

Rigid plastic foams are used commercially as shock absorbers in packaging
fragile items so that the concept of their use as aerial delivery energy
dissipators is not entirely new. Although these foams are satisfactory as
a package cushion, their behavior under dynamic or high velocity impact test
remains to be determined. A favorable characteristic of many of these plastic
foams is the ease of manufacture at a relatively low cost. In addition,
since many different types of items are air dropped, different densities of

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the same foam can be made to accommodate various items. This variation in density is accomplished simply by varying the proportion of the ingredients that are used in making the foam*. The utilization of one formula of plastic foam of different densities as energy dissipators for all dropped items instead of a different type of energy dissipator for each item offers many advantages. Hence, a variety of plastic foams and many different densities of the same foam were tested statically.

<div align="center">

Section A
Polyurethane Foams

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Flexible Polyurethane Foams

Polyester Urethane and Vibrafoam 41255

Since flexible polyurethane foams are among those commercial materials currently used in cushions and in automobile crash pads, static laboratory tests were conducted on two types of commercial polyurethane foams to investigate their properties as potential energy dissipators for high velocity aerial drop systems. Twelve samples of polyester urethane and nine samples of Vibrafoam 41255 were compressed to 25 percent deformation. The densities of the foam were found to be quite low: 2.7 lbs./cu.ft. for the polyester urethane and 3.9 lbs./cu.ft. for Vibrafoam 41255. As shown in Figures 2 and 3, both foams deformed similarly under compression. The data obtained shows that these flexible polyurethane foams are much too resilient to be used as energy dissipators for high velocity aerial drops. Although the loading compression curve is similar to that for an ideal cushioning material, the deforming stress is too low to effectively cushion heavy loads for drops because the initial weight of the items to be cushioned would be enough to deform the foam considerably.

Semi-Rigid Polyurethane Foams

Semi-Rigid Collofoam

Previous tests had shown that although flexible polyurethane foams deform at a relatively constant stress, they are entirely too soft and resilient for use as energy dissipators. As a result, a more rigid polyurethane foam was

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*Murray, G.E. and Levin, M. - Interim Report on the Development of Foamed Plastics as Energy Dissipators, Chemicals & Plastics Division, QM R&E Center, Natick, Mass. 1 July 1957.
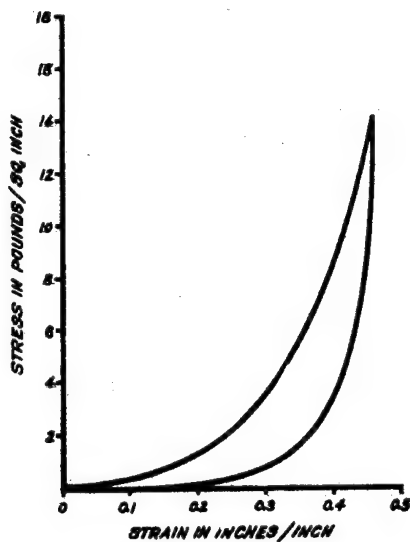
FIG. 1 FELT SHOCK PADS
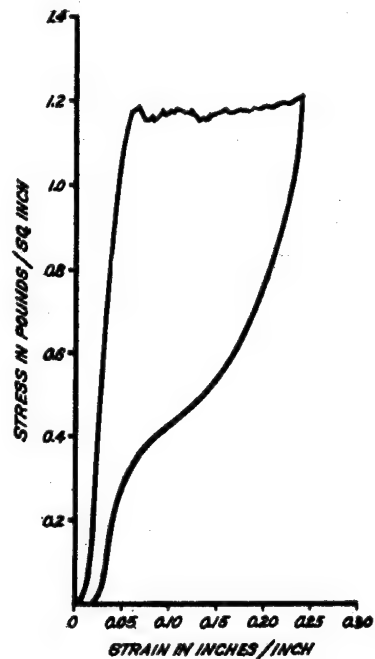TEST SPEED 20 INCHES / MINUTE
SIZE 4"x 4"x 1"

FIG.2 POLYESTER URETHANE
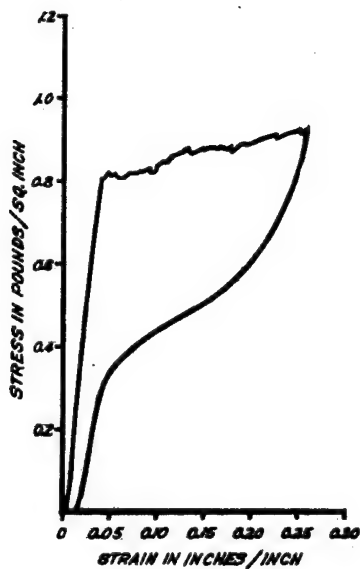TEST SPEED 0.2 INCHES / MINUTE
SIZE 1.1"x 1"

FIG.3 VIBRAFOAM 412.55
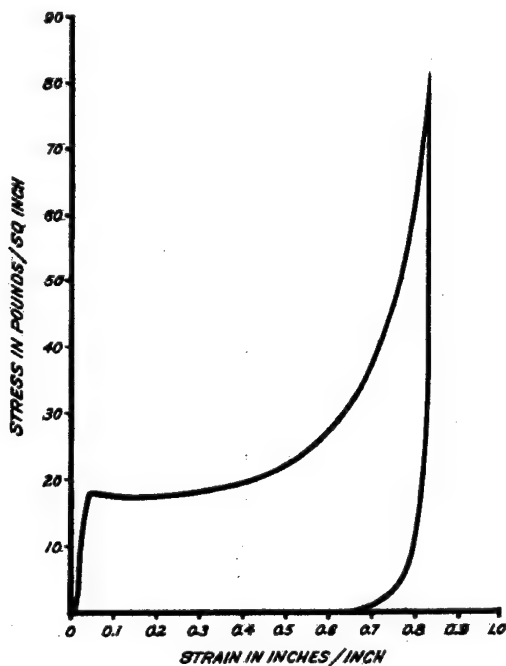TEST SPEED 0.2 INCHES / MINUTE
SIZE 1.1"x 1"

FIG.4 SEMI-RIGID COLLOFOAM
TEST SPEED 2 INCHES / MINUTE
SIZE 4"x 4"x 2"

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tested to determine its potential as a cushioning material. Nine samples of semi-rigid Collofoam were compressed to a bottoming point at 80 percent deformation. The data obtained seems to indicate that sample size and speed of testing may have some effect upon the final results. The graph in Figure 4 shows that the initial portion of the loading curve is essentially rectangular in shape. Upon further compression, the stress increases rapidly with a small amount of deformation since the sample bottoms and the material begins to pack into a solid mass. The amount of energy dissipated is fairly high since the resilience of the foam is low while the deforming stress remains relatively constant up to about 50-70 percent deformation. As a result, static compression tests indicate that semi-rigid Collofoam is a potential energy dissipator for use in high velocity aerial drops when extremely large amounts of kinetic energy must be dissipated.

Rigid Polyurethane Foams

Rigid Collofoam

Since it was observed that a semi-rigid polyurethane foam would dissipate more energy than a flexible polyurethane foam, the assumption follows that a rigid foam should dissipate more energy than a semi-rigid foam. Hence, a rigid polyurethane foam was investigated for its cushioning properties. Sixteen samples of rigid Collofoam were compressed to a bottoming point at 55 percent deformation. In all tests, the foam packed into a firm mass instead of disintegrating upon compression. As a result, the stress (Figure 5) continued to rise with further crushing of the sample. The amount of energy dissipated is relatively high and the resilience very low. Thus, data obtained from the static tests indicate that due to the high maximum stress, rigid Collofoam might not be a suitable energy dissipator for all of the items that are presently being considered for aerial delivery. However, as the energy dissipated is quite high, this foam may be a suitable cushion for items with high fragility limits. In addition, since the density is quite high and the foam packs quickly upon compression, a lower density material would be more suitable as a cushion since it would not pack or bottom until a higher percent of the initial volume of cushion has been deformed.

Section B
Vinyl Foams

Flexible Vinyl Foam

Vinyl Foam 505

Along with the polyurethane foams, flexible vinyl foams have also been commercially used in cushions and as an insulating material. Since static laboratory tests have shown that some polyurethane foams may be potential energy
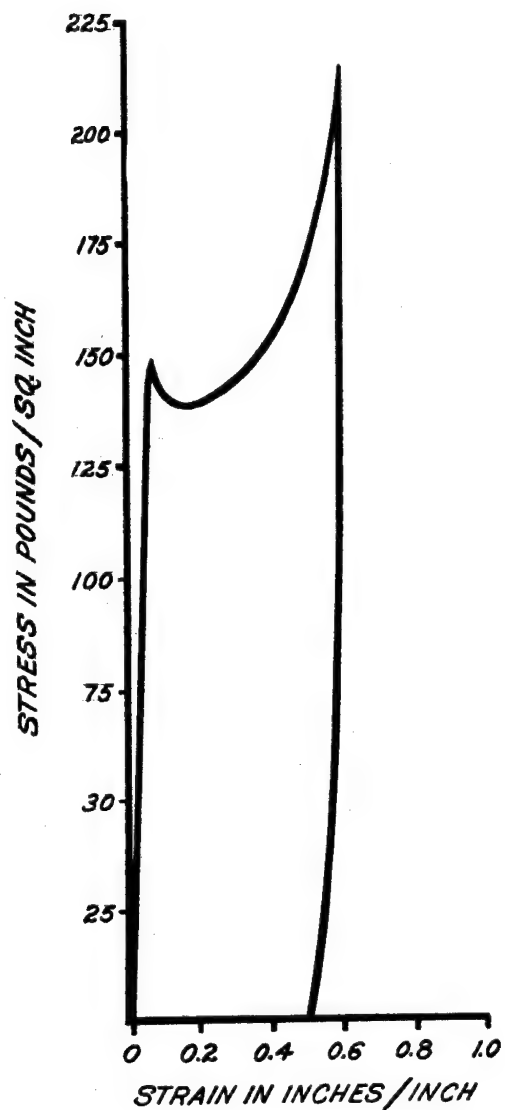
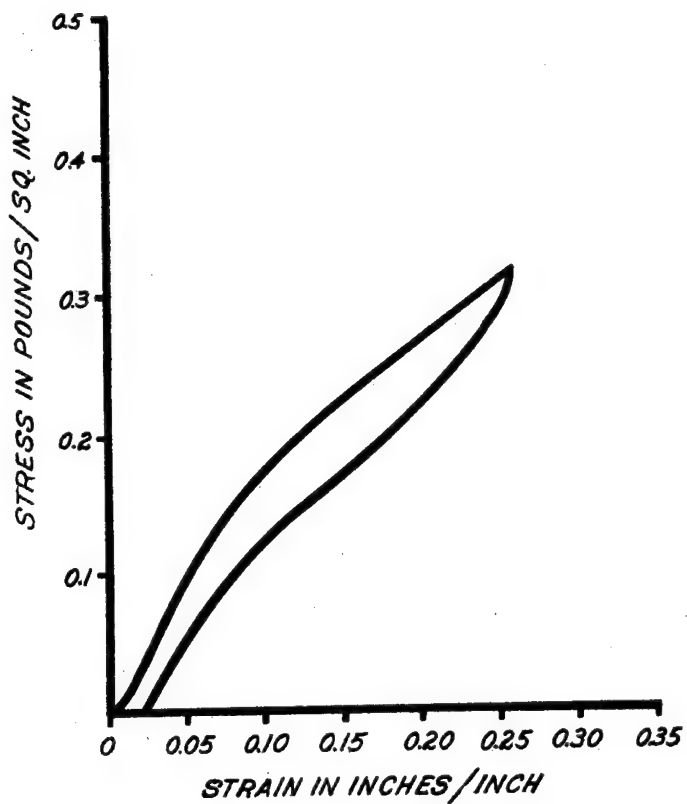FIG.5 RIGID COLLOFOAM
TEST SPEED 0.2 INCHES /MINUTE
SIZE 4"x 4"x 1"

FIG.6 VINYL FOAM 505
TEST SPEED 0.2 INCHES /MINUTE
SIZE 1.1"x 1"

dissipators, a vinyl foam was tested to determine whether it should be considered as a cushioning material. Twelve samples of Vinyl foam 505 were compressed to a deformation of 25 percent. The values obtained for the maximum stress and the amount of energy dissipated are very low while the resilience is extremely high. This is demonstrated in figure 6 where the area under the hysteresis loop is very small and the unloading curve is similar to that of the loading curve. Therefore, Vinyl foam 505 is too resilient to serve as an energy dissipator as the initial weight of the item to be cushioned deforms the foam considerably.

Semi-Rigid Vinyl Foam

Flutterstock

A similar situation exists for flexible vinyl foams and the polyurethane foams as these flexible materials are unsuitable for use as energy dissipators. Therefore, a more vinyl rigid foam was tested to determine whether it may be considered as a potential cushioning material. Samples of various sizes were tested at several compression speeds. The material bottomed at approximately 83 percent deformation and in some instances, sample size and speed of testing seemed to effect the results. The amount of energy dissipated is low as indicated by the small area enclosed by the hysteresis loop (Figure 7). Although the maximum stress may be within the range of the items presently considered for aerial delivery, the resilience is far too high to consider the use of this material as an energy dissipator.

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Section C
Polyethylene Foam

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Flexible Polyethylene Foam

Experimental Plastic Q4139.2

Polyethylene is used in the manufacture of many articles because if its moisture resistance and its low cost. As plastic foams should be ideal cushioning materials polyethylene was foamed for experimental test. A piece of foamed polyethylene was compressed to 82 percent deformation to determine its energy dissipation properties. The curve in Figure 8 shows that the area under the hysteresis loop is small while the unloading curve is similar to the loading curve. Hence, foamed polyethylene is unsuitable for use as an energy dissipator due to low energy dissipating values along with a high resilience of 72.4 percent.
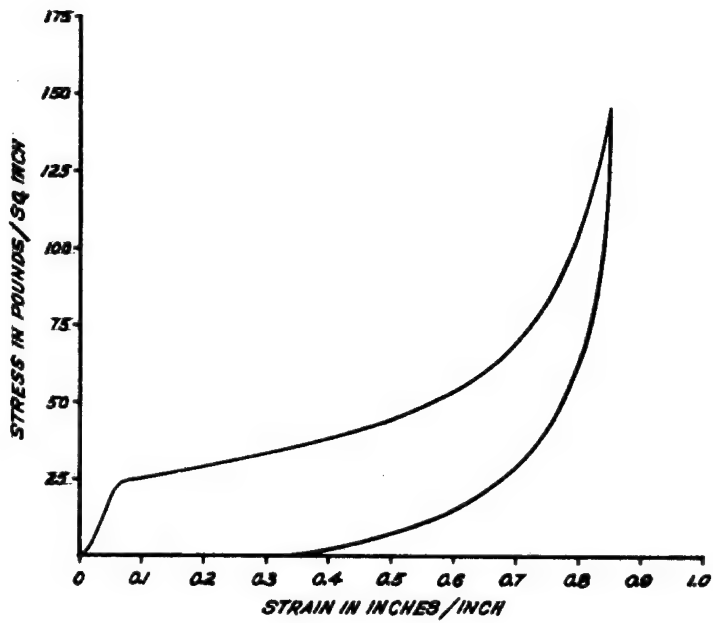
FIG.7 FLUTTERSTOCK
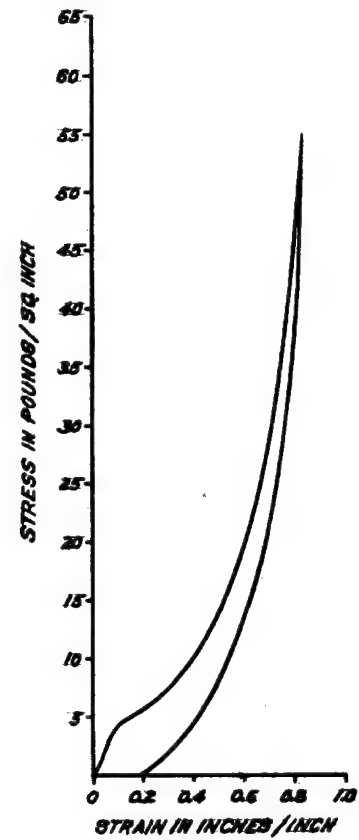TEST SPEED 0.2 INCHES/MINUTE
SIZE 4"x4"x1"

FIG.8 EXPERIMENTAL PLASTIC Q 4139.2
TEST SPEED 2 INCHES/MINUTE
SIZE 3.5"x3.5"x1"

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Section D
Polystryene Foams

Commercial Polystyrene Foam

Styrofoam 22

The commercial uses of Styrofoam 22 are many and varied. Since it is a rigid thermoplastic material, resistant to moisture and a poor heat conductor, it is used for low temperature insulation. In addition, its low density of 1.6 lbs./cu.ft. and shock absorbing characteristics makes it a useful packaging material. Hence, since it is rigid, lightweight, and absorbs a certain amount of shock, Styrofoam 22 was investigated as a potential energy dissipator. A total of 150 samples of various sizes was tested at several compression speeds. In many instances, a change in testing speed effected the results. Disregarding the effect of speed, values of stress, energy dissipation, and resilience are shown as averages in table I. The phenomenon was noted, that, regardless of the initial thickness of the foam sample, the stress and energy dissipation values per unit volume are identical at the same percent of deformation. For example, at 30 percent deformation, the maximum stress for each thickness is the same although obviously, the one inch thick samples were deformed only 0.33 inches while the five inch thick samples were compressed 1.67 inches. This observation would seem to indicate that if the stress and energy dissipation values per unit volume were obtained for one thickness at different amounts of compression, identical values might be obtained for different thicknesses of the material at the same percentage of deformation. The tabulated data and the curve depicted in Figure 9 shows that the maximum stress is fairly constant only to 50 percent deformation so that the curve is essentially rectangular in shape. Upon further compression to 80 percent deformation, the stress rose to about twice its initial value indicating that only one-half of the cushion thickness could be utilized efficiently. Hence, static tests show that Styrofoam 22 may be considered as an energy dissipator since the resilience is low and the stress is well within the desirable range of values.

Self-Extinguishing Polystyrene Foam

Styrofoam 33

Sytrofoam 33 is a rigid self-extinguishing polystyrene foam that is tinted blue for purpose of identification. Since its density of 2 lbs./cu.ft. is greater than that of Styrofoam 22, the foam was tested to determine the differences in stress and energy dissipation values. In all, 137 samples of various sizes were tested at several speeds. It is noted that the speed of testing is significant only in some instances. A comparison of the curve obtained for Styrofoam 33 (Figure 10) with that of Styrofoam 22, (Figure 9) shows that the two materials behave similarly under compression. The averaged data in Table II shows that here, too, regardless of the initial thickness of the sample, the stress and energy dissipation values per unit volume are the same providing the percent deformation is identical although the total amount of deformation is different. The average values of stress and energy dissipation are slightly higher than those obtained for Styrofoam 22 while the resilience remains the same. Hence, Styrofoam 33 may also be considered a potential energy dissipator since the resilience is low and the stress is within the range of desirable values.

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TABLE I

STYROFOAM 22

Deformation	Thickness	Maximum stress	Energy dissipated per initial vol.	Energy dissipated per crushed vol.	Resilience
%	in.	lbs./in^2	in.lbs./in.^{3}	in.lbs./in.^{3}	%
30	1	32.5	6.17	21.6	11.3
30	2	39.1	8.79	30.1	8.30
30	3	34.0	8.05	26.6	6.93
30	4	35.1	8.58	28.9	6.34
30	5	33.5	8.31	28.7	5.36
50	1	37.4	13.2	27.9	7.21
50	2	43.9	17.2	35.1	5.08
50	3	38.7	14.9	30.0	4.70
50	4	40.6	15.3	30.8	5.93
50	5	36.2	15.8	31.7	3.25
75	1	59.3	24.9	30.6	3.78
80	2	114	35.1	42.6	2.03
80	3	93.2	29.8	37.4	4.65
80	4	86.8	30.0	37.5	3.10
80	5	87.7	28.0	35.1	3.80
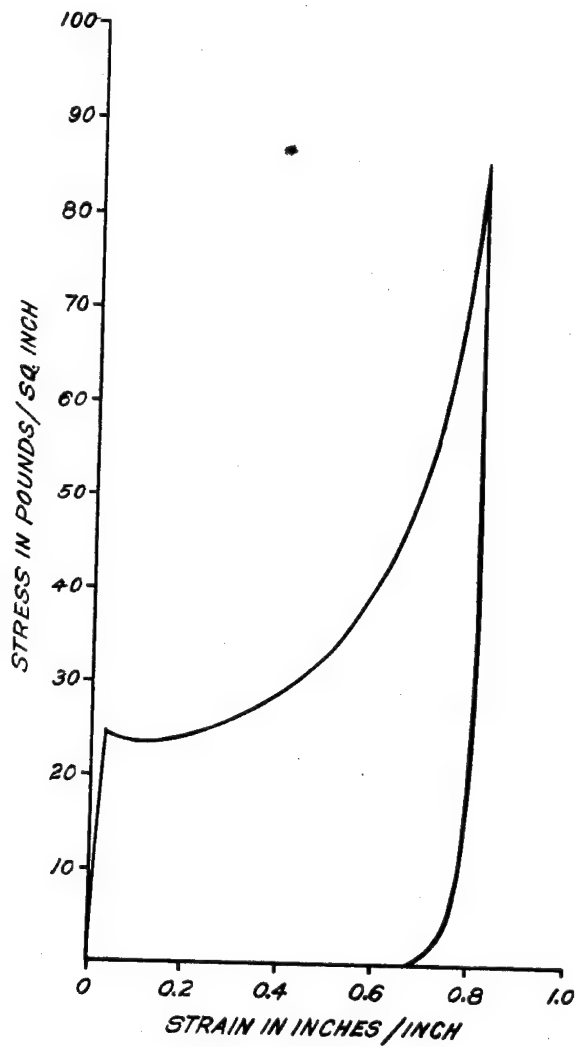
FIG. 9 STYROFOAM 22
TEST SPEED 0.2 INCHES/MINUTE
SIZE 4"x4"x4"
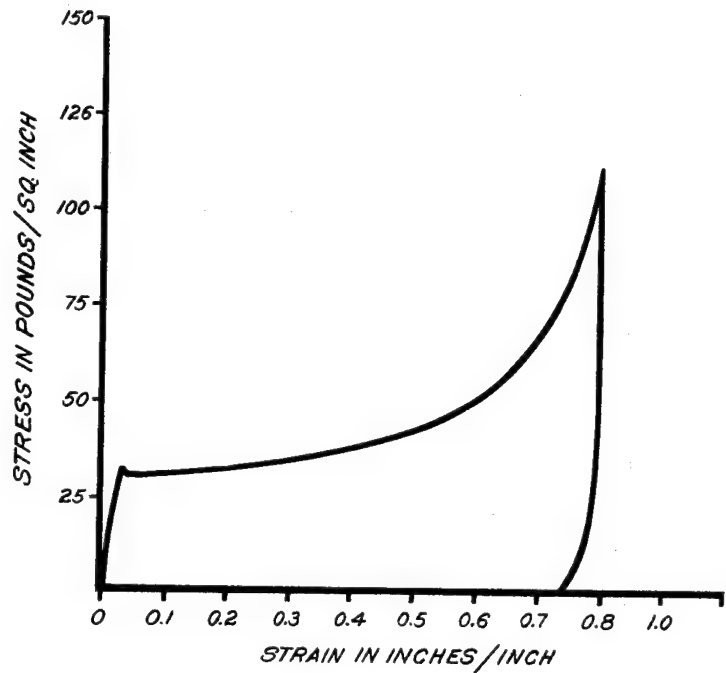
FIG. 10 STYROFOAM
TEST SPEED 2 INCHES/MINUTE
SIZE 4"x4"x5"

TABLE II

STYROFOAM 33

Deformation	Thickness	Maximum stress	Energy dissipated per initial vol.	Energy dissipated per crushed vol.	Resilience
%	in.	$lbs./in.^2$	$in.lbs./in.^3$	$in.lbs./in.^3$	%
30	1	40.1	9.16	31.7	7.43
30	2	45.6	10.4	34.0	6.82
30	3	36.3	8.51	28.8	9.08
50	1	46.3	18.2	36.9	3.47
50	2	50.7	20.8	42.2	2.74
50	3	48.9	17.1	34.5	7.01
50	4	51.5	20.3	43.1	3.08
50	5	48.6	16.6	33.3	7.46
75	1	71.9	31.4	42.3	2.89
70	2	61.4	30.5	44.1	2.27
80	2	256	42.4	53.0	1.84
80	3	117	35.8	44.5	2.51
80	4	111	36.0	45.3	2.69
80	5	107	33.9	42.6	2.20

Experimental Polystyrene Foams

Experimental Plastics Q103.15 and Q103.21

Since tests on low density rigid polystyrene foams indicated their possibility as energy dissipators, an investigation was conducted on a higher density foam to determine the effect of density upon the properties of the cushioning material during compression. One hundred and twenty nine (129) experimental plastic (Q103.15) samples and twenty six (26) experimental plastic (Q103.21) samples of various sizes were tested at several compression speeds. The bottoming point of both materials was reached at 60 percent deformation. Again, disregarding the effect of speed which appeared to be significant in some instances, the averaged data is shown in table III. Similarly to the Styrofoams, different thicknesses of 3 lbs./cu.ft. density, experimental plastic Q103.15 were found to have the same unit energy and stress values at the same percentage of deformation. Figures 11 and 12 show that both materials deform similarly under compression with a relatively constant stress and a small amount of resilience. From the tabulated data, it is noted that the stress and energy dissipation values of 4 lbs./cu.ft. density experimental plastic Q103.21 are higher while the resilience remains the same than for the lighter material. It is concluded that both of these foams may be considered as potential energy dissipators because of their high energy dissipation value, constant compressive stress and low resilience.

Expandable-In-Place Polystyrene Foam

Experimental Plastic Q865.2

Experimental plastic Q865.2 is a foamed-in-place polystyrene that is furnished in the form of small beads containing an expanding agent. Upon application of heat, the material may be expanded to any density, shape or size desired. Since the foam can be easily fabricated and only the beads need to be shipped to the point of use, the cost of transportation is low due to decreased bulk. Moreover, as the foam produced has many of the characteristics of Styrofoam, experimental plastic Q865.2 was investigated for use as an energy dissipator. Six samples of 1.7 lbs./cu.ft. and four of 4.4 lbs./cu.ft. densities respectively were measured. The lower density material was compressed to a bottoming point of 70 percent and the heavier foam to 60 percent deformation. The data obtained (Figures 13a and 13b) show that the stress and energy dissipation values increases with density while the resilience decreases. Although the stress of the lighter material is within the fragility range of the items currently considered for aerial delivery, the resilience is too high for the foam to be effective. On the other hand, while the resilience of the heavier material is low, the stress increases almost threefold. Thus, its applicability depends entirely on the fragility limit of the cushioned items since the stress is barely within the range of desirable values.

TABLE III

EXPERIMENTAL PLASTIC Q103.15

Deformation	No. Tested	Thickness	Maximum stress	Energy dissipated per initial vol.	Energy dissipated per crushed vol.	Resilience
%		in.	lbs/in^2	$in.lbs/in.^3$	$in.lbs./in.^3$	%
30	24	1	83.1	15.6	55.3	5.65
50	24	1	90.1	33.7	69.2	5.07
30	24	2	85.0	19.2	65.3	4.99
50	24	2	89.4	36.6	74.8	3.42
60	24	2	104	44.9	76.2	3.95
75	9	2	153	65.2	93.5	1.78

EXPERIMENTAL PLASTIC Q103.21

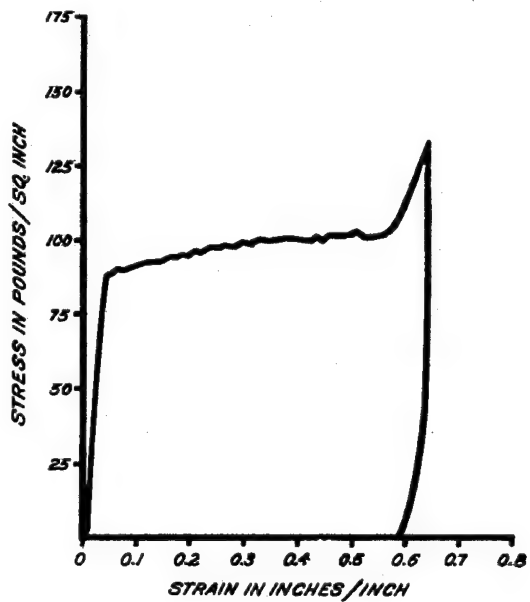| Percent deformation	No. Tested	Thickness	Maximum stress	Energy dissipated per initial vol.	Energy dissipated per crushed vol.	Resilience
%		in.	$lbs./in^2$	$in.lbs/in.^3$	$in.lbs./in.^3$	%
30	6	2	148	36.4	123	6.96
50	6	2	173	74.5	150	4.61
55	4	2	175	73.4	135	7.52
60	6	2	195	86.3	145	5.34
70	4	2	244	101	109	10.8

FIG. II EXPERIMENTAL PLASTIC Q 103.15
TEST SPEED 2 INCHES / MINUTE
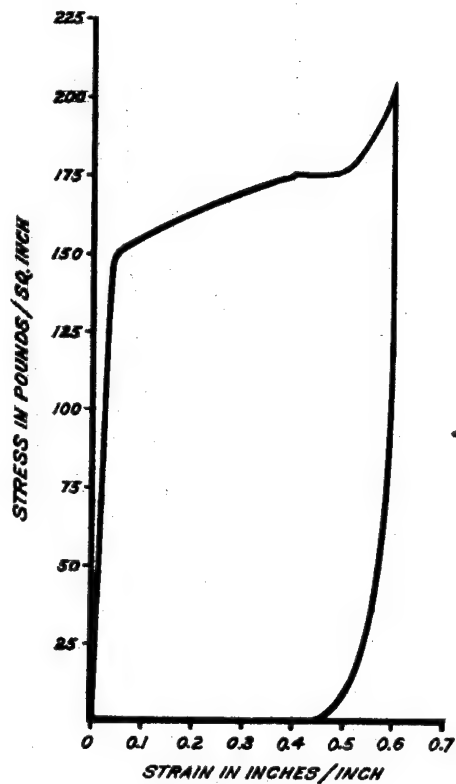SIZE 4"x 4"x 2"

FIG. 12 EXPERIMENTAL PLASTIC Q 103.21
TEST SPEED 2 INCHES / MINUTE
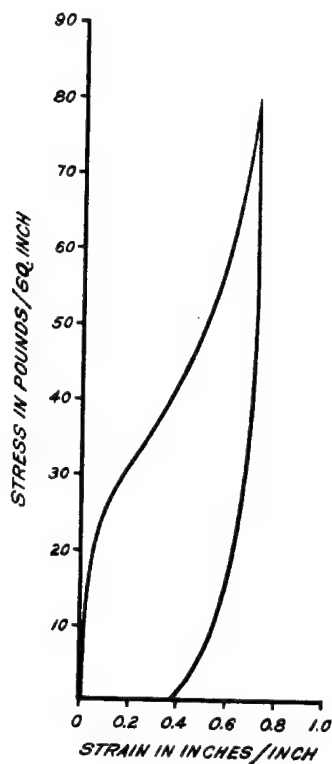SIZE 4"x 4"x 2"

FIG.13A EXPERIMENTAL PLASTIC Q 865.2
TEST SPEED 2 INCHES / MINUTE
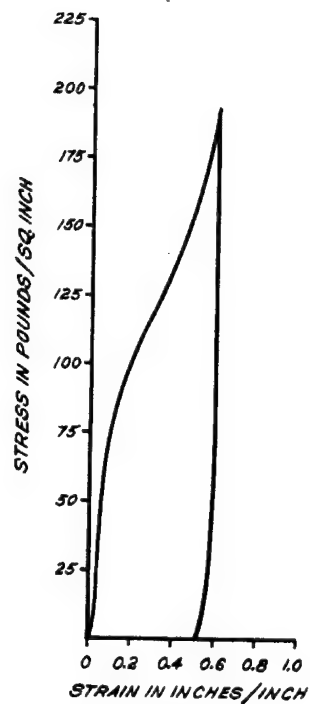SIZE 4"x 4"x 1"
DENSITY; 2 LBS./CU. FT.

FIG.13B EXPERIMENTAL PLASTIC Q 865.2
TEST SPEED 0.2 INCHES / MINUTE
SIZE 4"x 4"x 2"
DENSITY; 5 LBS./CU. FT.

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Section E
Acrylate Foam

Rigid Acrylate Foam

Foamed Plexiglas

Since it has been established that rigid plastic foams may be used as energy
dissipators, the performance of an acrylate foam as a cushioning material was
investigated. Nine samples of experimental foamed Plexiglas were tested at various
speeds to a bottoming point at 50 percent deformation. In all cases, speed of
testing seems to have no effect upon the data. Although the resilience is low
and the area under the curve (Figure 14) is quite large so that foamed Plexiglas
appears to be a potential energy dissipator, the maximum stress obtained is far
above the fragility limits of the items presently considered for aerial drop.
This may be due to the fact that the minimum density available was 8.0 lbs./ft.^{3}.

Section F
Epoxy Resin Foam

Rigid Epoxy Resin Foam

Eccofoam FP

With the development of foamed-in-place plastics, Eccofoam FP, a foamed-in-
place liquid epoxy resin was investigated for its properties as a potential energy
dissipator. Three one-inch cube samples of 17 lbs./cu.ft. density were compressed
and the bottoming point reached at 68 percent deformation. Although the foam ex-
hibited zero resilience and the curve (Figure 15) is partly rectangular in shape,
it is not suitable as an energy dissipator for the items currently considered for
aerial delivery due to its extremely high stress value and high density.

Section G
Glass Fiber

Resin Impregnated Glass Fiber

Fiberglas Honeycomb

The use of paper honeycomb as a cushion in field tests indicated that a
honeycomb type material may be an effective energy dissipator. Hence, considera-
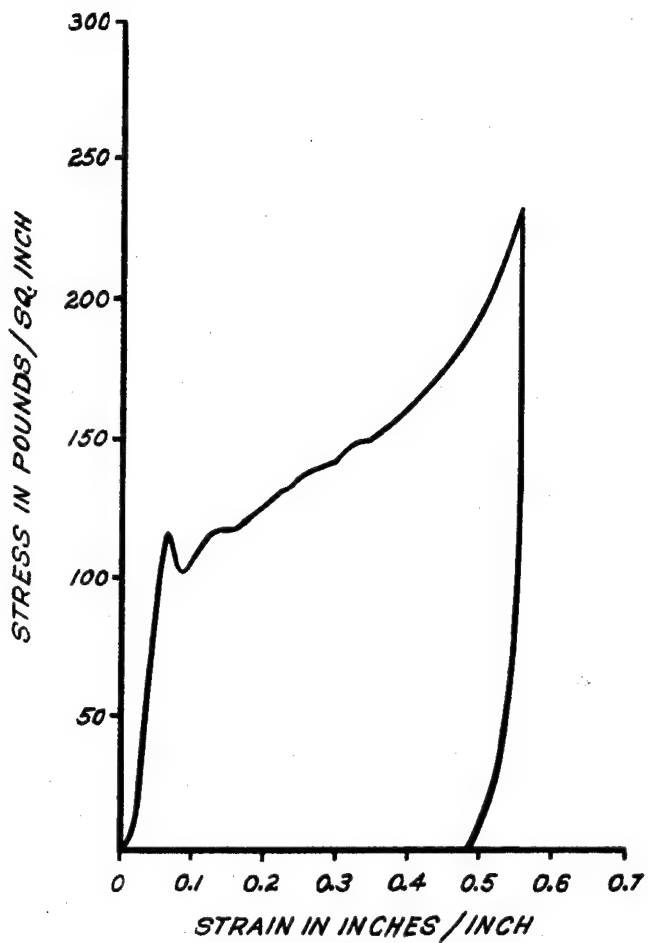tion was given to a resin impregnated glass fiber with a honeycomb structure.

FIG. 14 FOAMED PLEXIGLAS

TEST SPEED 2 INCHES / MINUTE
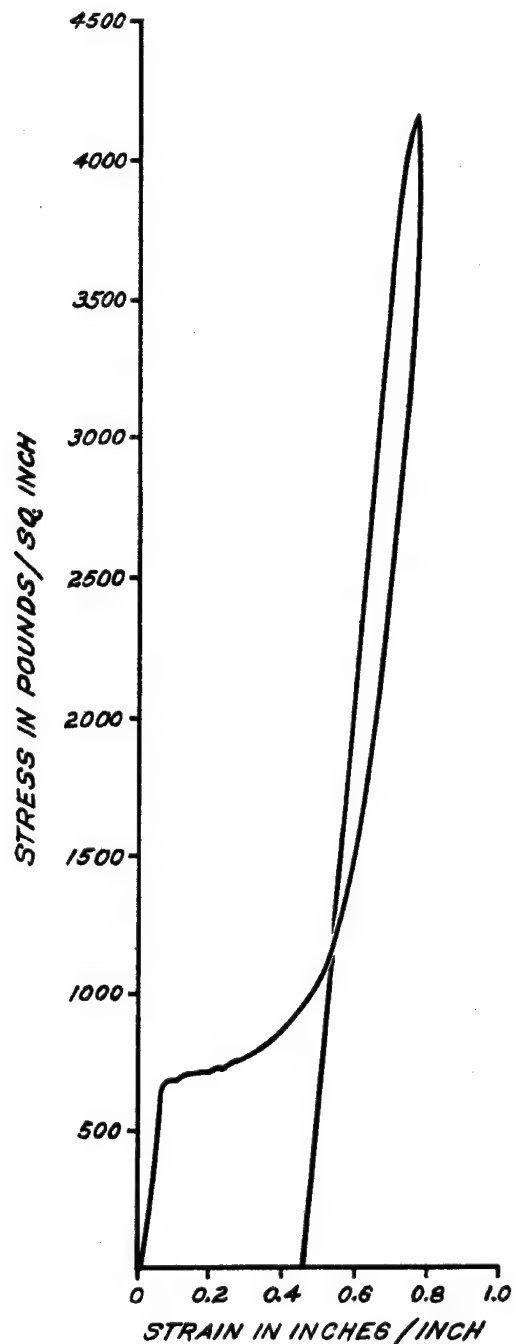
SIZE 1"x1"x1"

FIG. 15 ECCOFOAM FP

TEST SPEED 20 INCHES / MINUTE

SIZE 1"x1"x1"

This material is more rigid than paper honeycomb and might give a higher stress and energy dissipation value per unit volume. Five cubic samples were compressed to a bottoming point at 90 percent deformation. Figure 16 shows that Fiberglas honeycomb deforms similarly to paper honeycomb and the curve obtained is fairly rectangular in shape with a constant stress until a very definite bottoming point is reached. Resilience is negligible in all tests. The tests indicate that Fiberglas honeycomb may be considered as a potential energy dissipator because of high energy dissipation value and constant stress during compression.

PART III   INORGANIC MATERIALS

Introduction

Many types of inorganic materials have been used for the same applications as foamed plastics. They have been employed as structural materials as well as shock absorbers in packaging fragile items because of their high compressive strength and rigidity. They have been used extensively as insulating materials due to their heat resistant properties. A consideration of their compressive strength and rigidity properties made it appear advisable to determine whether a number of inorganic materials are potential energy dissipators for use in high velocity aerial drops.

Section A
Silicaeous Materials

Fibrous Fireproof Silicate Blocks

Asbestos Blocks

Previous static laboratory tests had shown that materials with honeycomb type structures have a tendency to crush with a relatively constant stress. This was observed in tests made on aluminum, fiber glass, and paper honeycombs where the cell walls tend to crinkle upon compression. Thus, it follows that tests should be made on materials with cell shapes other than hexagonal in order to determine whether they crush in a similar manner. Eight asbestos blocks (Figure 17a) were compressed to a very definite bottoming point at 78 percent deformation. In all cases, resilience is negligible since the samples break down and finally pack into a firm mass (Figure 17b). The curve in (Figure 17c) corroborates the fact that although the asbestos blocks do not have hexagonal shaped cells, the rectangular shaped compression curve obtained is similar to that for a honeycomb material in that the stress is relatively constant with a definite bottoming end point. Since no knowledge of the effect of sample facing was available, tests were made using two unfaced samples stacked on top of each other to form a block. During compression, the specimens telescoped into each
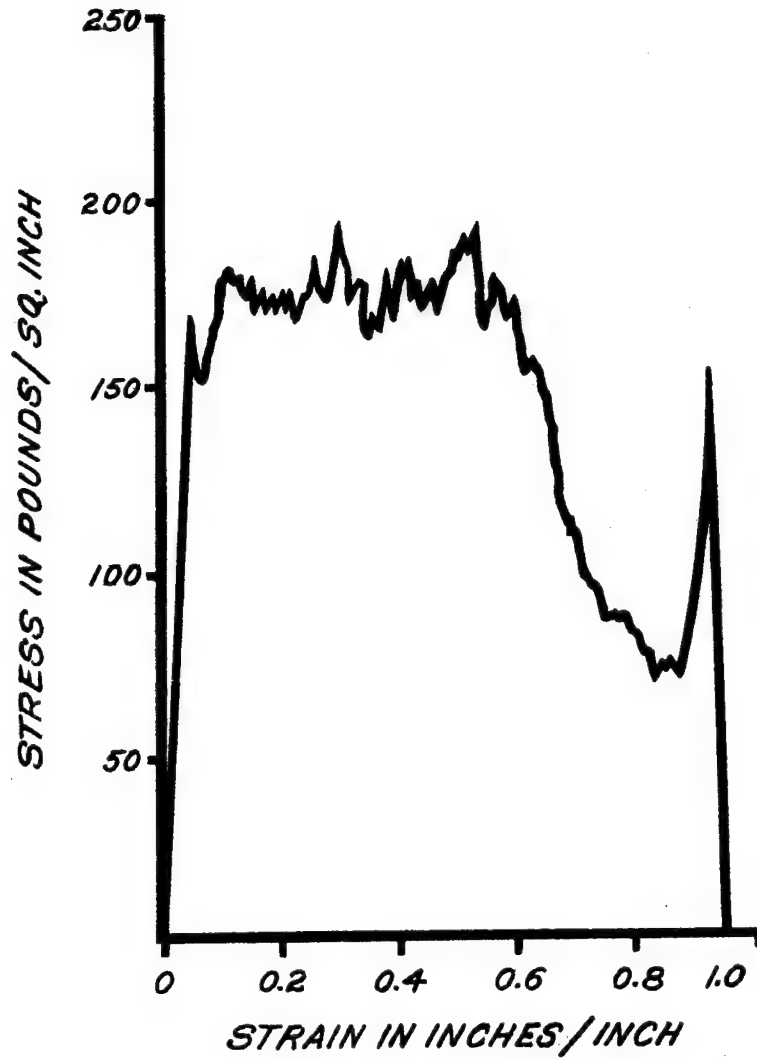
FIG.16 FIBERGLAS HONEYCOMB

TEST SPEED 20 INCHES/MINUTE

SIZE 3"x 3"x 3"
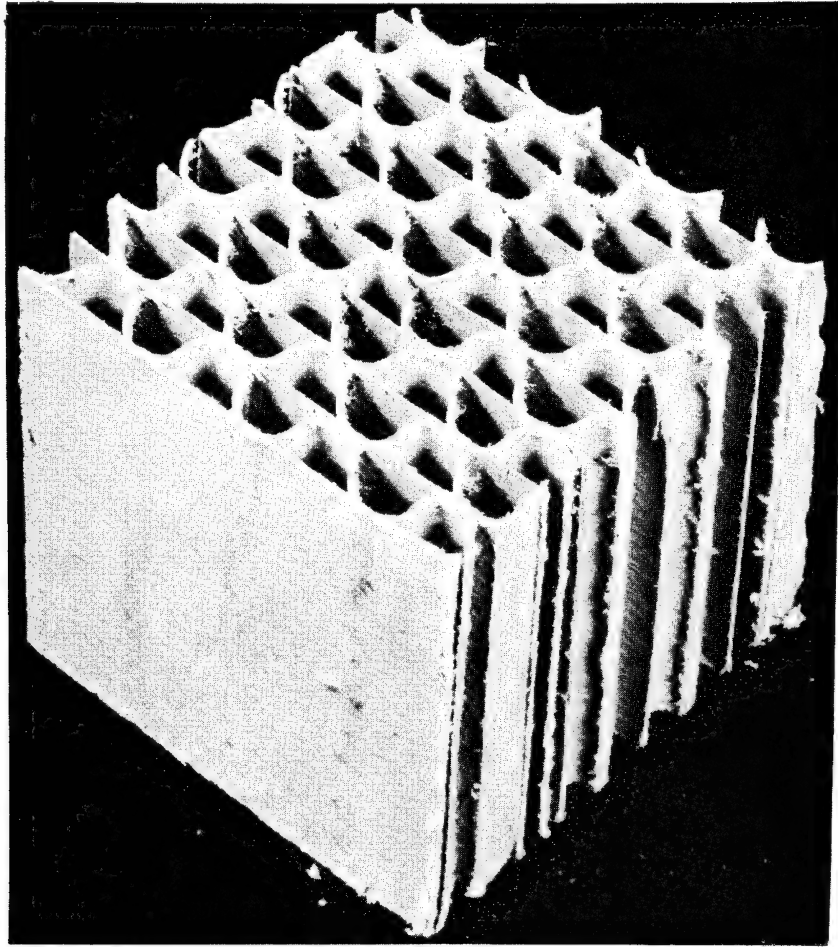
Figure 17a - Asbestos blocks before compression.
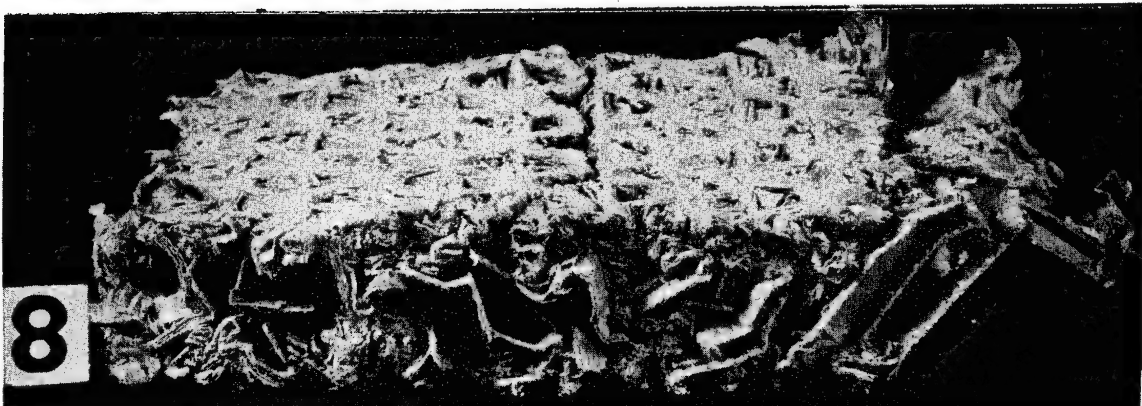
Figure 17b - Same asbestos blocks as above after being compressed to a
very definite bottoming point at 78 percent deformation.
Resilience is negligible since sample breaks down and packs
into a firm mass.

FIG. 17C ASBESTOS BLOCKS
TEST SPEED 20 INCHES / MINUTE
SIZE 4"x 4"x 4"

FIG.17D ASBESTOS BLOCKS

TEST SPEED 20 INCHES/MINUTE

SIZE 4"x4"(2"+2")

STRAIN IN INCHES/INCH

STRESS IN POUNDS/SQ. INCH

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other to form a very dense mass before actual crushing occurred. This is observed in Figure 17d where the low constant force depicts this telescoping action and the abrupt rise in force to almost twice its value depicts the actual crushing of the sample. Hence, all the pieces have only a 50 percent deformation since the density doubled. These tests show that although asbestos blocks 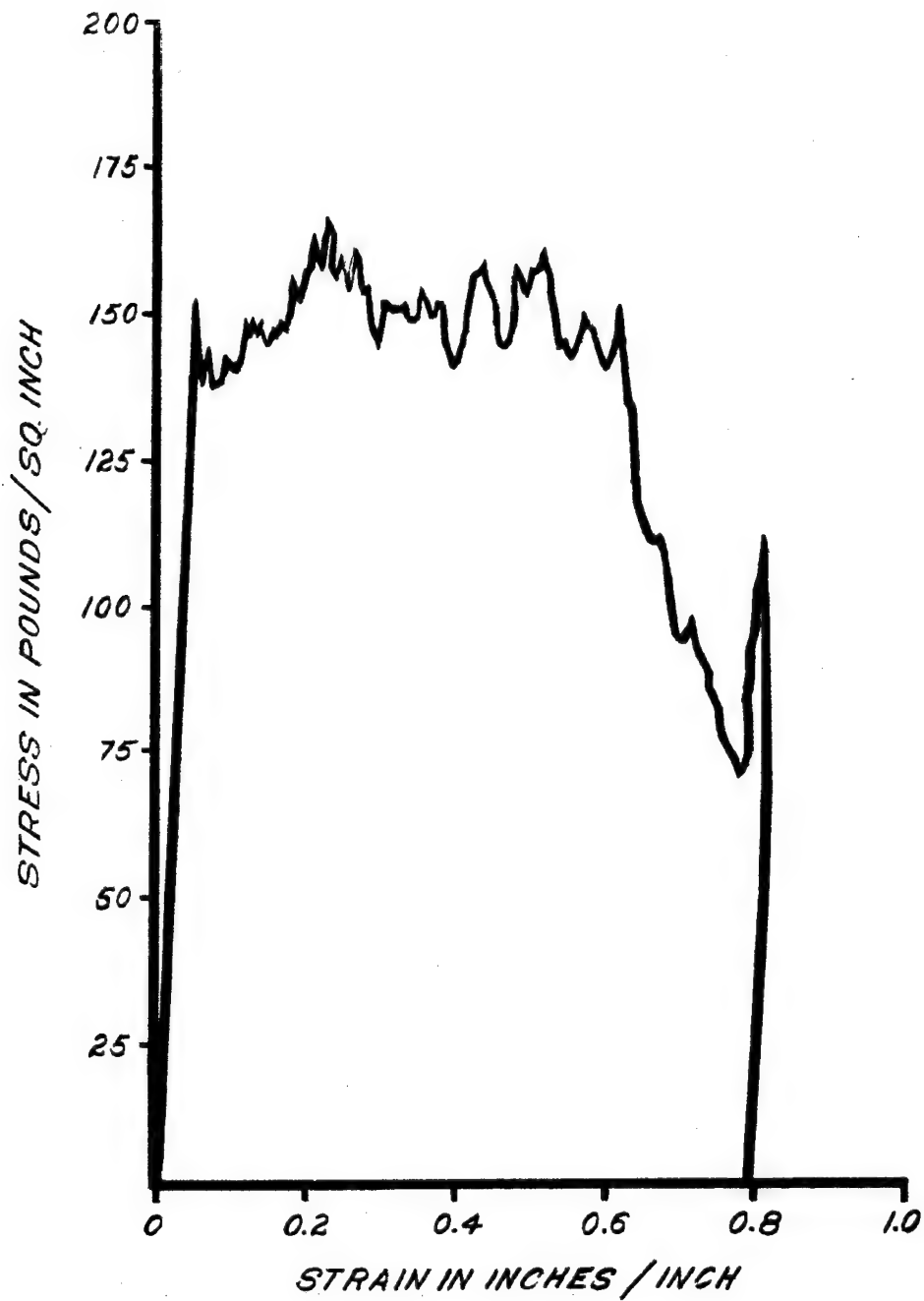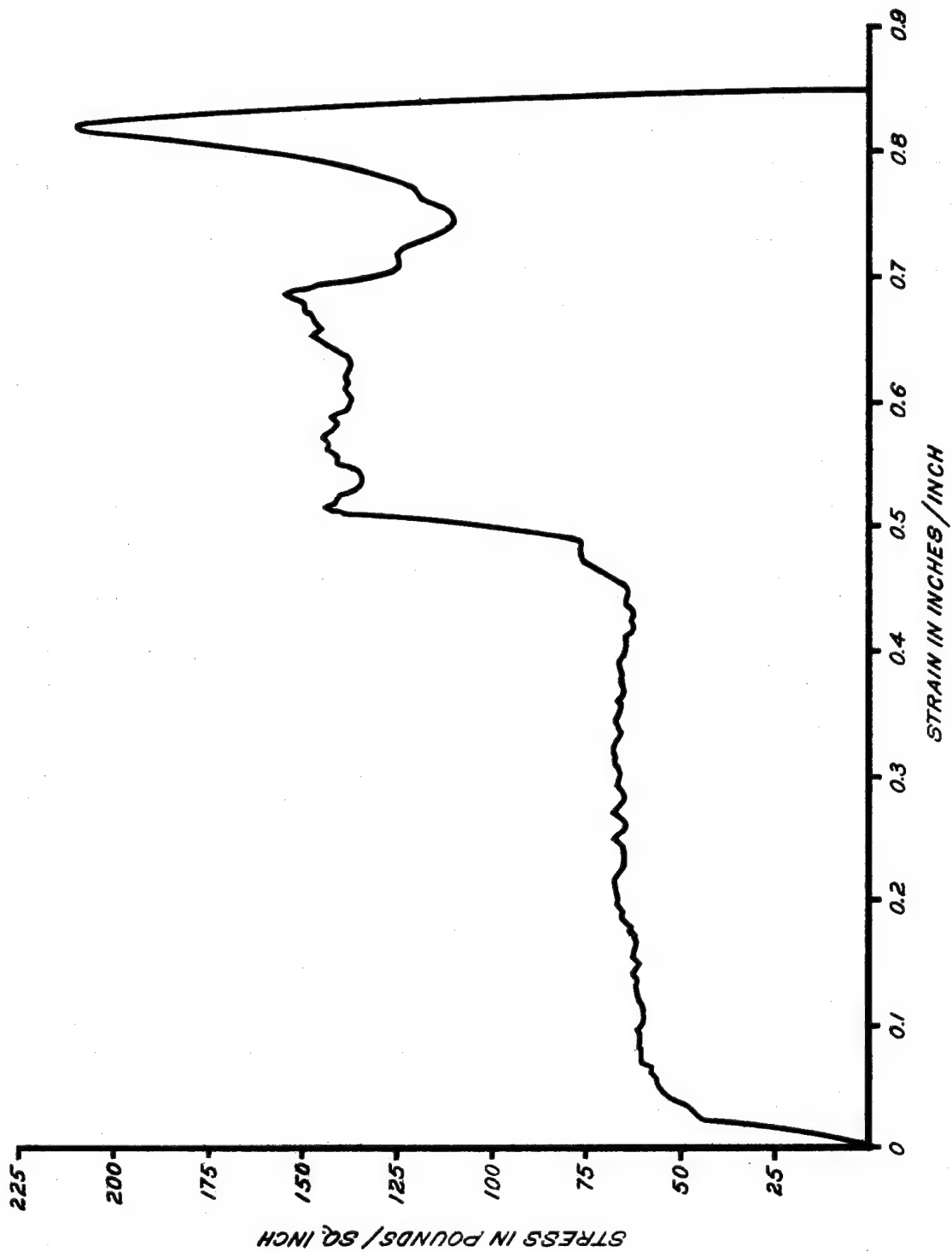do not have hexagonal shaped cells, they behave similarly to honeycomb material in that they deform at a relatively constant stress. Hence, in spite of high density, this block material may be considered as a potential energy dissipator since the values obtained are within the prescribed limits. However, if layers of blocks are used, a facing must be employed as each block tends to telescope.

Hydrous Calcium Silicate Blocks

Kaylo and Kaylo-20 Block Insulations

Samples of Kaylo material, a rigid hydrous calcium silicate heat insulator reinforced with asbestos fibers, were static tested since actual free-fall drop tests made by the manufacturer seemed to indicate that the material may be a good energy dissipator. In these tests, items such as canned foods were packed in cartons lined with Kaylo material and dropped from a height of 1000 to 1500 feet onto a concrete runway. A few cans ruptured while a few were dented. An investigation was conducted on two types of blocks; Kaylo and Kaylo-20. Both materials were compressed to a bottoming point at 69 percent deformation. Although resilience is negligible with high energy dissipation values, the density and stress for both materials are above acceptable limits to consider their use as energy dissipators.

Commercial and Experimental Foamglas

A number of materials tested shows that different types of rigid foam insulating or sandwich core materials may be good energy dissipators. Hence, Foamglas was selected for static testing since it is a unicellular fire-proof material that is used extensively in insulation and construction work. Twenty-seven (27) samples of experimental Foamglas, 8 lbs./cu.ft. density and two hundred and ten (210) samples of commercial Foamglas 9 lbs./cu.ft. density were tested in various sizes at several speeds to a definite bottoming point at 85 percent deformation. It is observed from the curves in figures 19a and 19b that the stress increases gradually with deformation until a maximum is reached at about 50 percent deformation. Upon further compression, the stress declines until a bottoming point of 85 percent deformation is reached. A cursory statistical analysis was made from the data in tables IV and V on the effect of speed of testing, density of material, sample size and thickness upon the stress and energy dissipation values. This analysis shows that the density of the material

TABLE IV

COMMERCIAL FOAMGLAS

Testing speed	No. tested	Sample size	Maximum stress	Energy dissipated per initial vol.	Energy dissipated per crushed vol.	Resilience
inches/min.		in.	$lbs./in.^2$	$in.lbs./in.^3$	$in.lbs./in.^3$	%
0.2	10	3x3x1	191	113	134	0
2	10	3x3x1	176	105	124	0
20	10	3x3x1	232	130	158	0
0.2	10	3x3x2	207	141	161	0
2	10	3x3x2	228	149	172	0
20	10	3x3x2	231	158	181	0
0.2	10	3x3x3	197	131	152	0
2	10	3x3x3	230	149	173	0
20	10	3x3x3	230	152	176	0
0.2	10	4x4x1	169	102	121	0
2	10	4x4x1	180	107	127	0
20	10	4x4x1	209	128	148	0
0.2	10	4x4x2	145	102	118	0
2	10	4x4x2	162	113	130	0
20	10	4x4x2	185	124	145	0
0.2	10	4x4x3	215	151	172	0
2	10	4x4x3	206	140	160	0
20	10	4x4x3	214	147	171	0
0.2	10	4x4x4	194	136	154	0
20	10	4x4x4	186	140	160	0

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TABLE V

EXPERIMENTAL FOAMGLAS

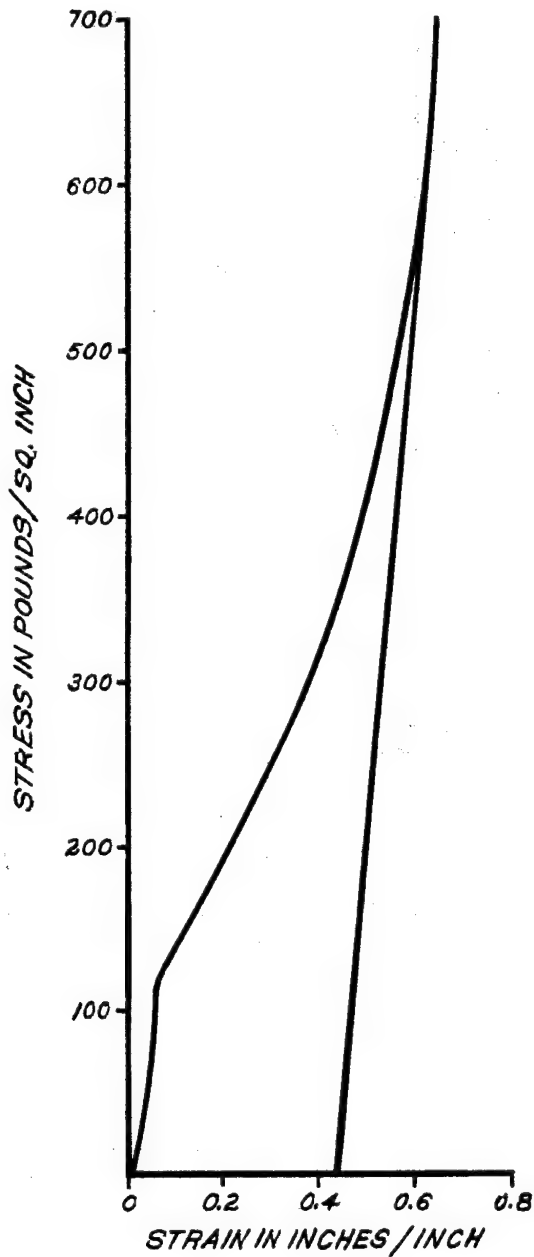| Test speed inches/min	0.2	2	20	
No. tested	9	9	9	
Weight	2.30	2.36	2.40	oz.
Width	4.00	3.99	3.58	in.
Length	3.98	4.01	3.98	in.
Thickness	2.01	1.95	1.99	in.
Density	7.80	8.21	8.29	lbs./cu.ft.
Maximum force	1968	2781	2593	lbs.
Maximum stress	124	174	163	lbs./sq.in.
Energy dissipated	2463	3403	3425	in.lbs.
Energy dissipated per initial volume	76.9	109	109	in.lbs./cu.in.
Energy dissipated per crushed volume	89.4	126	126	in.lbs./cu.in.
Resilience	0	0	0	percent
Final force	474	733	756	lbs.
Final stress	29.8	45.8	47.7	lbs./sq.in.
Deformation	1.73	1.68	1.72	in.

FIG. 18A KAYLO BLOCK
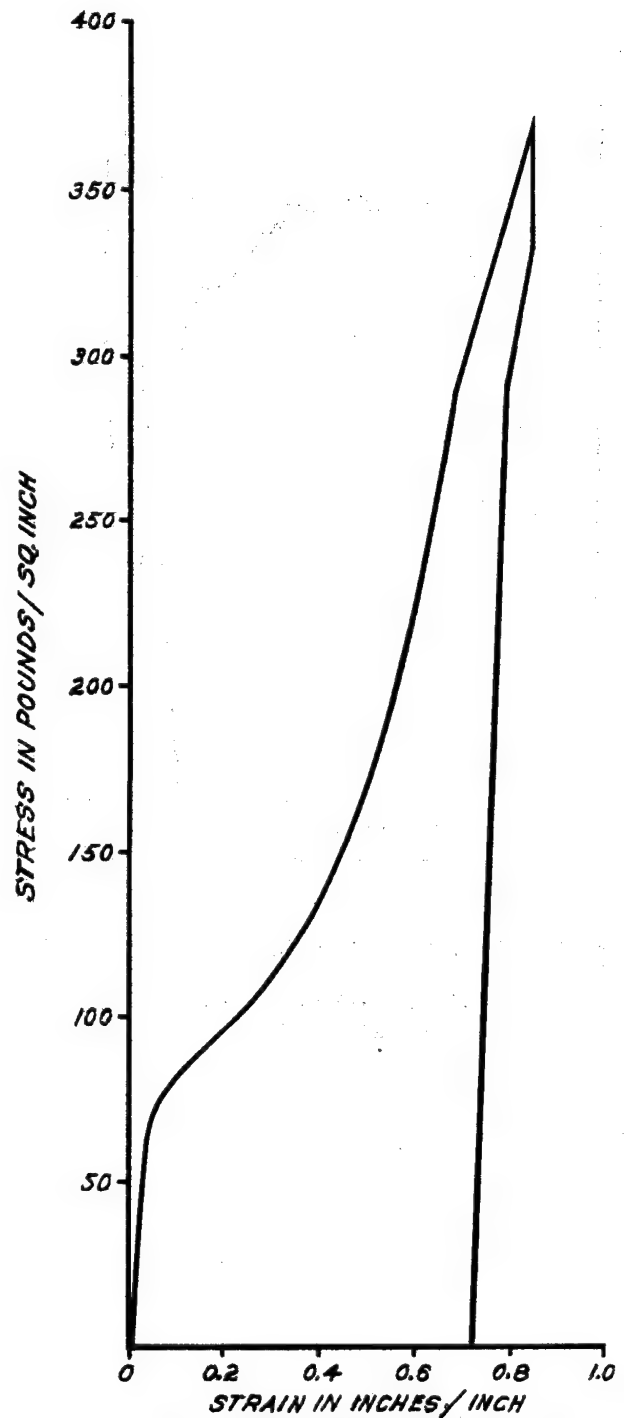TEST SPEED 2 INCHES / MINUTE
SIZE 3"x 4"x 1.3"

FIG. 18B KAYLO-20 BLOCK
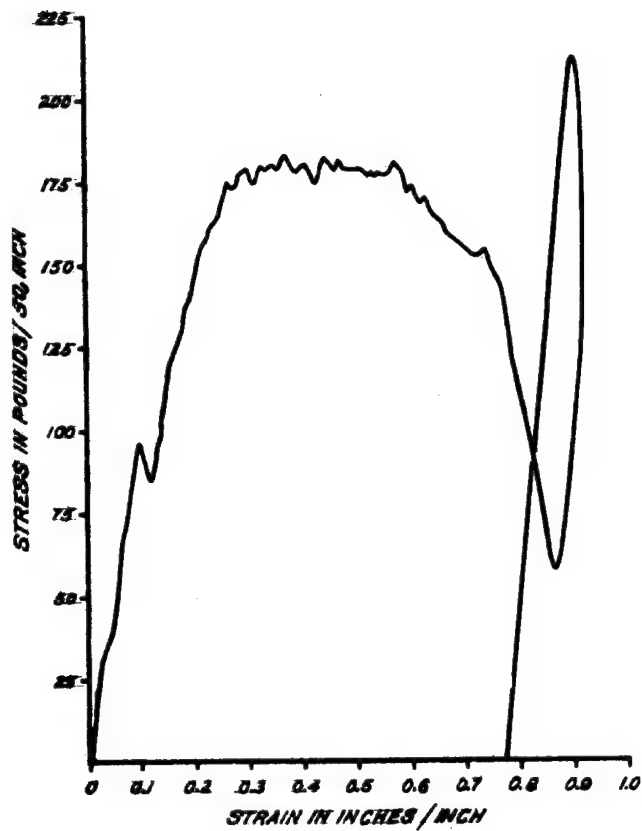TEST SPEED 20 INCHES/MINUTE
SAMPLE SIZE 3"x 4"x 1.3"

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FIG.19A EXPERIMENTAL FOAMGLAS
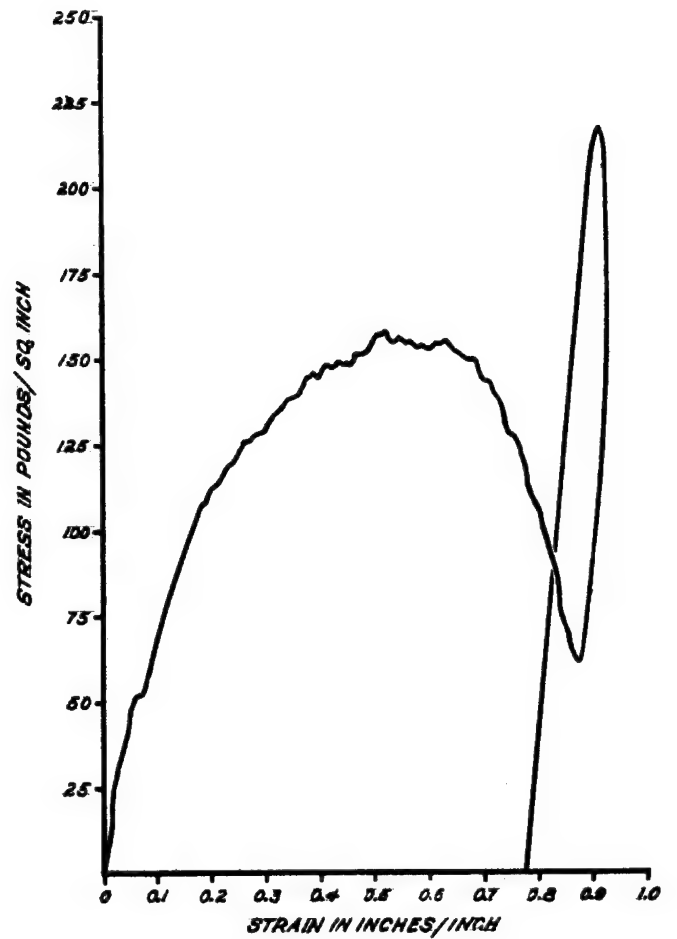TEST SPEED 20 INCHES / MINUTE
SIZE 4"x 4"x 2"

FIG.19B COMMERCIAL FOAMGLAS
TEST SPEED 20 INCHES/MINUTE
SIZE 4"x 4"x 2"

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has no significant effect upon stress or energy dissipation value. However, Foamglas is very brittle and crumbles readily and hence this observation may not be valid due to the fact that while the two samples tested have nearly equal densities the foam structure varied considerably. A much lighter Foamglas of 3 to 4 lbs./cu.ft. density should be tested to determine the effect of density. In all cases, speed, sample size and thickness are quite significant. The stress and energy dissipation values increase with higher testing speeds and greater sample thickness. On the other hand, these values decrease with an increase in sample size. At present, there is no satisfactory explanation as to the cause of this phenomena. As both materials powdered upon compression, resilience is negligible. In conclusion, experimental Foamglas is considered a potential cushioning material since the amount of energy dissipated per unit volume is fairly high, resilience is negligible and the compressive stress falls within the prescribed limits. The utilization of commercial Foamglas as a cushioning material is entirely dependent upon the fragility limit of the cushioned items since the stress obtained is at the maximum limit of the range for those items presently considered for drop.

Section B
Metals

Foamed Aluminum

Since solid blocks of metal are far too rigid to be considered as a potential cushioning material, a foamed sample of one of the lighter metals, aluminum, was tested to determine whether it is a potential energy dissipator for use in high velocity aerial drops. The foamed aluminum sample crushed well beyond its bottoming point and since resilience is negligible, all values are calculated to the bottoming point at 69 percent deformation. Figure 20 shows that the curve is fairly rectangular in shape only to about 30 percent deformation and upon further compression, the material packs into a solid mass. The test shows that foamed aluminum is unsuitable for use as an energy dissipator because of its extremely high stress. However, for densities below 36 lbs./cu.ft., stress values may be lower. This conjecture has not been confirmed since lighter density foamed aluminum is unavailable.

Empty Metal Cans

Empty metal cans* were tested in compression to determine two things :

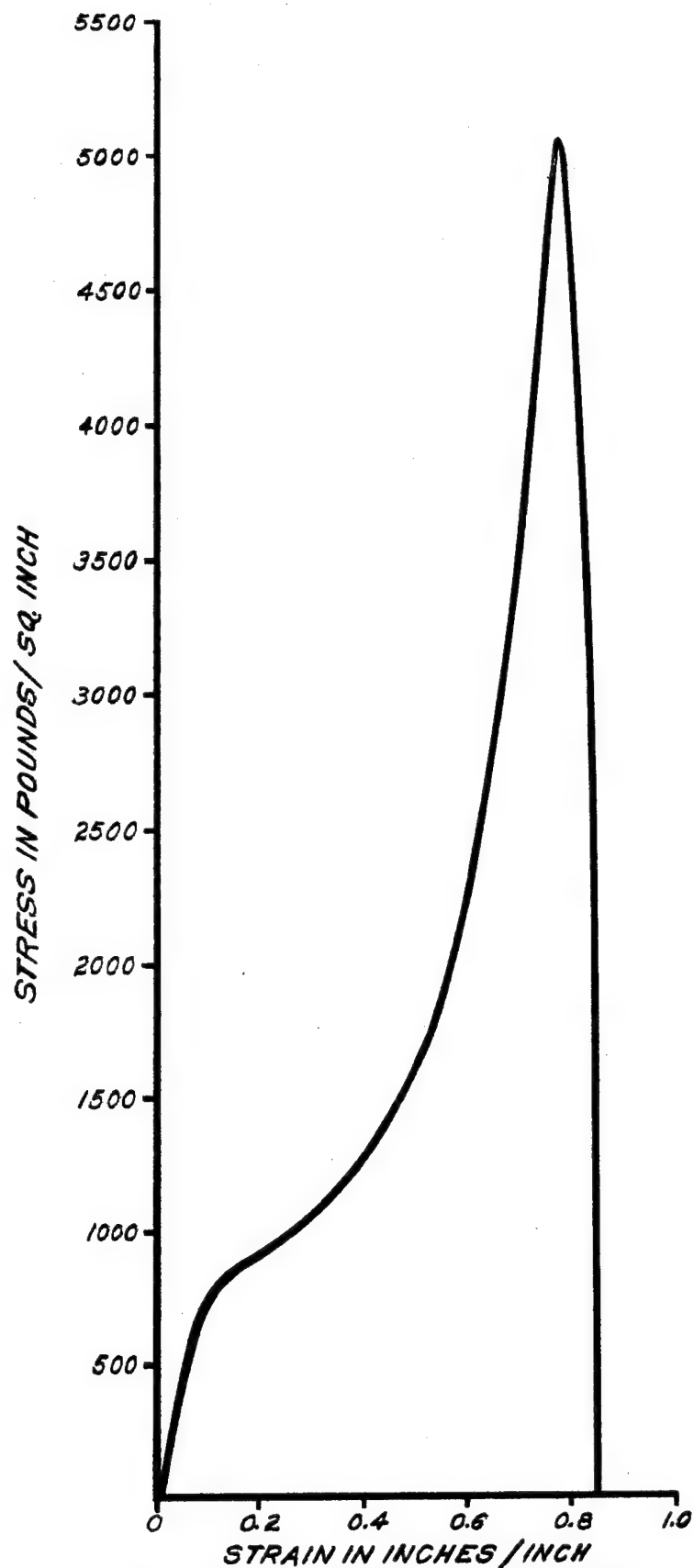*Beer cans with hole punched in top.

FIG. 20 FOAMED ALUMINUM
TEST SPEED 20 INCHES/MINUTE
SIZE 1"x1"x1.3"

(1) potential as energy dissipators and (2) the strength of the can. These
two factors are important because in aerial drop of C-rations, the stress
required to initially rupture the can must be known as well as the energy
dissipating capability of the cushioning material used. In this way, require-
ments can be established for the screening of materials as potential energy
dissipators for C-rations. The objective is to design a drop system for C-
rations so that all the energy of the dropped item will be dissipated at a
constant stress or decelerated at a stress value slightly lower than the break-
ing strength of the can. Six empty metal cans were compressed at two test
speeds to complete failure and all the stress transmitted to the base plate.
During each of the tests, regardless of speed, initial failure was found to
occur at the can seams. Upon further compression, a crinkling effect took
place until the cans were completely crushed. Figure 21a shows an essentially
rectangular shaped curve where the can is compressed at a relatively constant
stress to a bottoming point at 81 percent deformation. In all cases, resilience
is negligible while the stress and energy dissipation values fall within the
desired limits. An extremely high initial stress of 318 lbs./sq.in. (Figure 21b)
occurs at the lower test speed, while at the higher speed, the stress required
to initially rupture the can is 110 lbs./sq.in. Thus, if the energy dissipator
behaves similarly under dynamic testing as in static testing, the cushion re-
quired would dissipate all the kinetic energy of the drop system at a constant
stress equal to the initial rupture stress of the can. Calculations can be
made to determine the total kinetic energy of the drop system as well as the
fragility factor of the cans according to equations 1 and 2*.

$$KE = 1/2 mV^2 \qquad\qquad\qquad \text{Equation (1)}$$

where: KE = Kinetic Energy in Foot-Pounds

m = Mass of Drop System in Weight/Gravity

V = Impact Velocity in Feet/Second

$$F = ma = \frac{Wa}{g} = WG \qquad\qquad\qquad \text{Equation (2)}$$

where: F = Force in Pounds

a = Deceleration in Feet/Second^2

W = Weight of Drop System in Pounds

g = Acceleration Due to Gravity, 32.2 Ft./Second^2

G = Fragility Factor of Load in Gravities (g's)

*Murray, G.E. - Basic Concepts on the Energy Dissipation of Cushioning Materials,
Technical Report CP-12, Chemicals & Plastics Division, QM R&E Center, Natick,
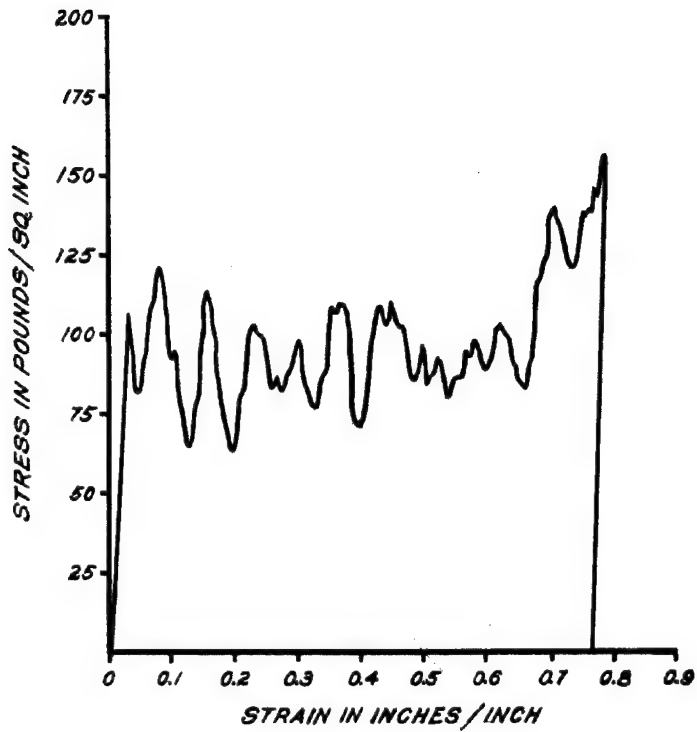Mass., April 1958

FIG. 21A METAL CANS
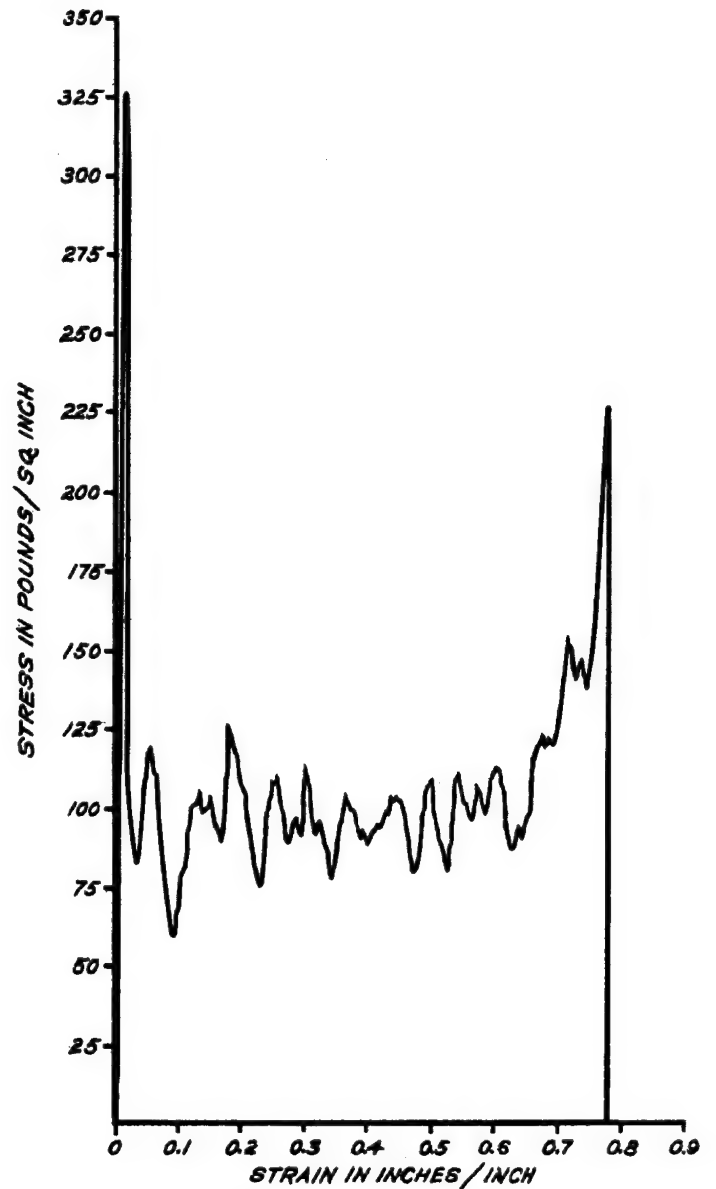TEST SPEED 20 INCHES / MINUTE
SIZE 2.6"x 4.8"

FIG. 21B METAL CANS
TEST SPEED 2 INCHES/MINUTE
SIZE 2.6"x 4.8"

However, in order to decelerate an object at a constant force without exceeding its fragility factor, the minimum permissible stopping distance must be determined. This is calculated as follows:

$$S = \frac{V^2}{2a} = \frac{V^2}{64G} \qquad \text{Equation (3)}$$

where: S = Deceleration Distance in Feet

V = Impact Velocity in Feet/Second

G = Fragility Factor of Load in Gravities (g's)

Thus a screening test can be used to select a material which will dissipate all the Kinetic energy (KE) of the drop system as calculated from equation (1) at a constant force slightly below the fragility factor, G, in equation (2), through a distance expressed in feet that is greater than (S) as calculated in equation (3). Since an essentially rectangular shaped, high deformation curve is obtained upon compression, metal cans may be considered as potential energy dissipators. As only a few static tests were made on cans, it is recommended that dynamic tests be made on C-rations to determine their fragility factor so that requirements can be established to select an efficient cushioning material.

PART IV   WOOD PRODUCTS

Introduction

Wood and wood products are among the most widely used materials in sandwich construction and packaging. These materials are good absorbers against shock and vibration encountered under usual shipping conditions. Therefore, these products were subsequently tested as potential energy dissipators for use in high velocity aerial drops.

Section A
Balsa Wood Blocks

Tests made by the supplier show that balsa wood is a useful material in the packaging of items for transit. Hence, samples of balsa wood were tested statically for their energy dissipating properties. Speed of testing has a pronounced effect upon the data (Figures 22a and 22b). At the lower testing speed, a peak stress is obtained which drops quickly as the sample begins to break down and pack. At the higher speed, the samples flew apart upon initial impact. Therefore, these tests show that balsa wood is unsuited as an energy dissipator since the amount of energy dissipated is very low and the bottoming point is reached at approximately 45 percent deformation.
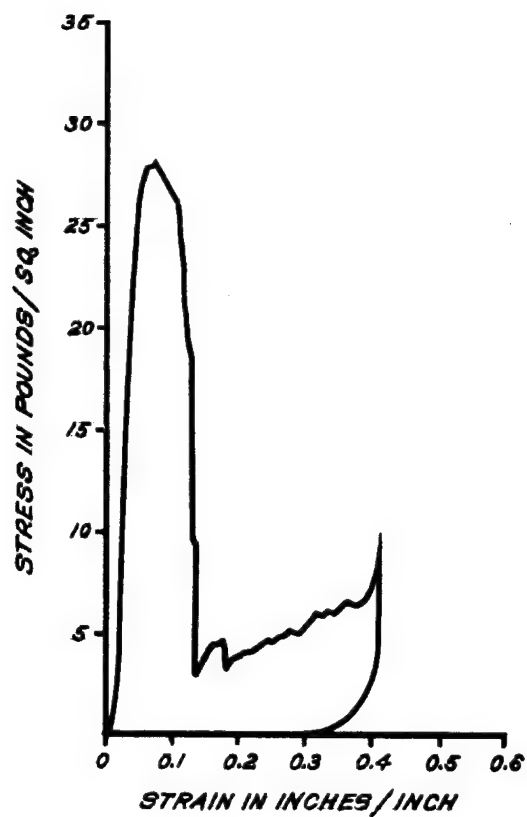
FIG. 22A BALSA WOOD BLOCK
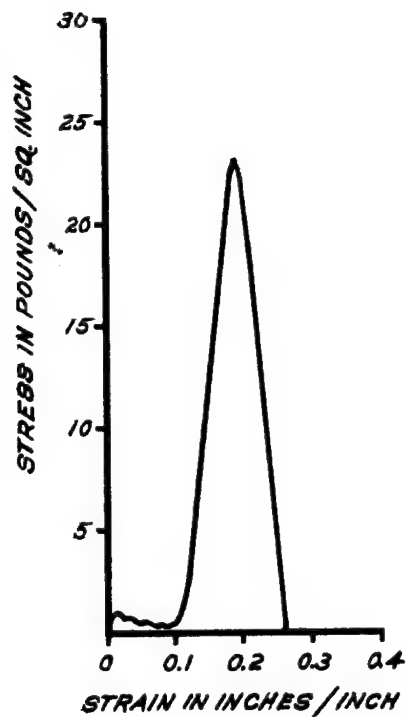TEST SPEED 2 INCHES / MINUTE
SIZE 4"x 4"x 2"

FIG. 22B BALSA WOOD BLOCK
TEST SPEED 20 INCHES / MINUTE
SIZE 4"x 4"x 2"

EXPERIMENTAL TEST METHODS

Cylindrical and rectangular foam samples of various sizes were cut and conditioned at 73.5 ∠ 4% R.H. in accordance with ASTM procedures. The compression apparatus used was a model TT-Cl Instron tester with a constant rate of crosshead movement. Hysteresis force-deformation curves were traced on an automatic high speed graphic recorder while the area under the curve was obtained with an automatic integrator operating simultaneously with the recorder. As some of the honeycomb materials have large open cells and do not represent a uniform cross section, four inch square samples were chosen and is the maximum sample size that the testing apparatus can accomodate. However, earlier tests were conducted to determine the correct sample size and speed as well as to investigate foams as potential energy dissipators. Various size samples were tested at speeds of 0.02, 0.2, 2, 10, and 20 inches/minute.

PROCEDURE FOR PREPARING AND TESTING SAMPLES UNDER COMPRESSION

1. Preparation of Samples

   a. Condition samples at 73.5 ∠ 2°F. and 50 ∠ 4% R.H. to constant weight.

   b. Number and measure the width, length and thickness of each sample.

   c. Weight each sample.

2. Testing Apparatus

   a. A constant rate of crosshead speed compression tester equipped with cycling controls and a recording device for tracing hysteresis stress-strain or force-deformation curves.

   b. An automatic integrator that records the area under the curve as it is being traced while not absolutely essential, is very helpful in minimizing the amount of work involved in the final calculations.

3. Procedure

   a. Compress one sample at 2 inches/minute speed to the greatest amount of deformation to which the sample can be subjected. The deformation point at which bottoming occurs is located on the curve and in addition, the initial peak force is also obtained.

b. Set the crosshead cycling controls so that the crosshead will compress
    a sample only to the bottoming point as obtained in 3a above.

c. Compress the rest of the samples to this predetermined amount of de-
    formation at 20 inches/minute speed.

4. Calculations

a. Record for each sample the weight, width, length, and thickness.
    From the curves obtained, tabulate the maximum force, energy dis-
    sipated, deformation, and initial peak force, if any.

b. From the data in 4a, calculate the density, maximum stress, energy
    dissipated per initial volume, energy dissipated per crushed volume,
    resilience, and initial peak stress, if any.

DEFINITIONS

"Bottoming" is said to occur when the sample has failed completely under
compression at a very definite end point at which under further compression
the stress increases rapidly with little or no further deformation. For
materials which do not have definite compression end points, bottoming occurs
where a 100 percent increase in force increases the deformation by less than
2 percent. (ASTM Tentative methods of testing package cushioning). This may
be different from other definitions of "bottoming".

Resilience is the ability of the cushion to recover its size and shape
after deformation. It is expressed in percent of the ratio of the energy
returned to the energy applied to the load upon impact. Thus, the resilience
is 100 percent for an ideally elastic impact and is zero for an ideally in-
elastic impact.

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METHODS OF CALCULATION

Quantity	Units	Method
Weight	oz.	Weigh on a balance
Initial volume	cu. in.	Width x length x thickness
Density	lbs. / cu. ft.	$\dfrac{\text{Weight x 1728}}{\text{Initial volume x 454}}$
Maximum force	lbs.	Highest point on Instron curve x $\dfrac{\text{full scale load}}{10}$
Maximum stress	lbs. / sq. in.	$\dfrac{\text{Maximum force}}{\text{Area}}$
Deformation	in.	Length of chart from initial to final loading x $\dfrac{\text{crosshead speed}}{\text{chart speed}}$
Percent deformation	%	$\dfrac{\text{Deformation}}{\text{Initial volume}}$ x 100
Crushed volume	cu. in.	Width x length x deformation
Energy Dissipated	in. lbs.	Area under Instron curve x $\dfrac{\text{full scale load}}{10}$ x $\dfrac{\text{crosshead speed}}{\text{chart speed}}$
Energy dissipated per initial volume	in. lbs. / cu. in.	$\dfrac{\text{Energy dissipated}}{\text{Initial volume}}$
Energy dissipated per crushed volume	in. lbs. / cu. in.	$\dfrac{\text{Energy dissipated}}{\text{Crushed volume}}$
Resilience	%	$\dfrac{\text{Area under unloading curve}}{\text{Area under loading curve}}$ x 100

COMPARISON AND DISCUSSION

The data on all the materials tested is tabulated in Table VI. An average value of all tests is shown when only one size of sample was tested at one speed but the maximum and minumum values of the ranged results are tabulated when various size samples were tested at several speeds. Since the aerial delivery of C=rations is important, the numerical values obtained for the strength of the cans under the higher static testing speed is used as a basis to screen other materials (Table VI). These measurements are informative because dynamic tests have not been made to determine the strength of the metal cans in order to establish the criteria for the selection of a suitable cushioning material for delivery of C=rations. In accordance with the numerical values given for the cans, all the materials are grouped into three classes: (1) those which have definite potential as energy dissipators since they fall within the re= quired range of metal can values; (2) those which appear to be on the border line of the other two classes; and, (3) those whose values are too low or too high and consequently can be eliminated since there is no possibility of their being considered as cushioning materials for aerial delivery of C-rations.

Class (3) indicates that thirteen different materials are unsuitable for use as energy dissipators for C rations. Since felt, polyester urethane, Vibra= foam 41255 and vinyl foam 505 are so soft that they deform readily upon contact, the stress and energy dissipation values are too low and the resilience too high for their consideration as cushioning materials. While balsa wood blocks are fairly rigid, they are eliminated because of their low energy dissipation values. Although the stress of experimental polyethylene foam (Q4139.2) is within the desirable range of values, the amount of energy dissipated is low due to the high resilience of the foam. On the other hand, the stress values for foamed flexiglas, Eccofoam FP, Kaylo, Kaylo=20 blocks and foamed aluminum are much greater than the desired values. However, it may be noted that in each of these cases, the density is also extremely high. Thus, at lower densities, the stress values may be less so that the materials may possibly be applicable in aerial delivery work. Although the lighter density experimental plastic Q865.2 foam and Flutterstock are fairly rigid materials so that their stress and energy dissipation values fall within the prescribed limits, these foams are eliminated because of their high resilience. Based upon the above criteria, only eight out of 25 different materials tested merit consideration as energy dissipators. Semi-rigid Collofoam, Styrofoam 22, Styrofoam 33, experimental plastic Q103.15 and Fiberglas honeycomb are in group 1 and dissipate a fairly large amount of energy with little or no resilience. Moreover, since the stress is slightly lower than the breaking strength of a metal can, these five materials have the best potential as energy dissipators in the aerial delivery of C=rations. Although asbestos blocks and experimental Foamglas have no resilience and high energy dissipation values, their stress range

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TABLE VI

Materials	Maximum Stress lbs./in²	Energy Dissipated per Initial vol. in.lbs./in.³	Energy Dissipated per Crushed Vol. in.lbs./in.³	Resilience %	Density lbs./ft.³	Deformation %	Classification
Semi-Rigid Collofoam	76.4-93.4	19.6-27.0	23.6-34.0	5.26-6.38	3.2	80	1
Styrofoam 22	59.3-114	24.9-35.1	30.6-42.6	2.03-4.65	1.6	80	1
Styrofoam 33	61.4-117	30.5-36.0	42.3-45.3	2.20-2.89	2.0	80	1
Experimental Plastic Q103.15	90.1-104	33.7-44.9	69.2-76.2	3.95-5.07	3.0	60	1
Fiberglas Honeycomb	129	145	157	0	4.2	90	1
Asbestos Blocks	172	109	139	0	10	78	1
Experimental Foamglas	124-174	76.9-109	89.4-126	0	8.0	85	1
Metal Cans	150-162	88.0-82.2	101-108	0	12	81	1
Rigid Collofoam	191-228	60.8-85.2	109-143	4.62-5.57	6.5	55	2
Experimental Plastic Q103.21	195	86.3	145	5.34	4.0	60	2
Experimental Plastic Q865.2	178-235	63.2-79.7	107-135	2.54-3.45	4.4	70	2
Commercial Foamglas	145-232	102-158	118-181	0	9.0	85	2
Felt	17.3-30.2	1.12-2.62	2.23-5.70	35.0-37.1	9.1	50	3
Polyester Urethane	0.76-1.34	0.02-0.17	0.32-0.78	42.1-84.8	2.7	25	3
Vibrafoam 41255	0.79-1.08	0.06-0.08	0.25-0.32	59.0-63.5	3.9	25	3
Vinyl Foam 505	0.37-0.57	0.014-0.032	0.06-0.13	55.4-75.2	6.9	25	3
Flutterstock	78.6-186	18.6-29.9	24.5-37.2	53.3-41.9	3.1	83	3
Experimental Plastic Q4139.2	54.2	3.39	4.12	72.4	1.8	82	3
Experimental Plastic Q865.2	73.1	21.7	31.3	17.8	1.7	60	3
Foamed Plexiglas	236-245	67.2-71.0	134-143	3.86-5.28	8.0	50	3
Eccofoam FP	1679	518	762	0	17	68	3
Kaylo Block	590	203	290	0	14	69	3
Kaylo-20 Block	242	69.9	121	0	14	69	3
Foamed Aluminum	3803	963	1377	0	36	69	3
Balsa Wood Blocks	21.9-31.3	1.75-4.56	6.36-16.3	2.75-5.76	7.	45	3

is just within the breaking strength of the cans. As no knowledge is available on whether filled cans have higher or lower breaking strength than empty cans, these materials are classified as potentially suitable for use. Based on this assumption, empty metal cans are also placed in this category. Rigid Collofoam, experimental plastic Q103.21, higher density experimental plastic Q865.2 and commercial Foamglas form the second group of materials whose stress range is approximately equal or slightly above the breaking strength of the cans. Thus, utilization of these materials for energy dissipation is entirely dependent upon the fragility factor of the C-rations. However, even if these materials were found to be unsuitable for use with C-rations, they may be considered as potential energy dissipators for drop items with higher fragility factors because they exhibit little or no resilience and dissipate a large amount of energy per unit volume. Hence, a careful analysis of the data indicates that density plays a significant role in determining the resulting numerical values since the stress and energy dissipated increases with density. In addition, the data shows that cellular and foamed materials are better energy dissipators than solidly packed materials. This is due to the fact that each layer of cells or foam offers the same amount of resistance to compression, or stated in other terms the uncrushed portion of the sample remains relatively constant in density during compression until completion of the test or until bottoming occurs and the crushed portion packs. An analogous situation exists with materials composed of vertical columns of cells such as honeycomb where upon disintegration, a crinkling of the cell walls takes place under compression. Nevertheless, consideration must be given to the fact that even though some of the materials tested may be good energy dissipators, there remains the important questions of transportation, bulk and cost since many of the cushioning materials tested herein cannot be manufactured in the field.

CONCLUSIONS

Cellular and foamed materials have better energy dissipation characteristics than solidly packed materials since the compressive stress is more uniform. In many instances, static compression tests show that speed of testing, density, thickness and size of the test samples may be significant in determining the final stress and energy dissipation values.

RECOMMENDATIONS

1. Further investigation to determine whether Fiberglas honeycomb can be prepared in the field.

2. Further investigation of low density acrylate and epoxy resin foams.

3. Investigation of metallic cylinders as energy dissipators.

4. Standardization of the size of the test samples at 4" x 4" for static tests.

5. Standardization of the procedure for preparing and testing samples under compression.

ACKNOWLEDGEMENTS